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THE MAINTENANCE OF THE EQUILIBRIUM AS A FUNCTION OF THE CENTRAL NERVOUS SYSTEM.[1]

PROFESSOR HEINRICH OBERSTEINER.

It is difficult for man to exist, more difficult than would be supposed from a superficial consideration. In his earliest childhood man stands—or, better, lies—here in the world and finds before him a series of tasks for which he is but partially fitted. Fortunately, we bring with us into the world a most finely elaborated organism, by which from the beginning a great part of this work is essentially lightened. For example, our hearts beat regularly, we breathe rhythmically, and so forth. For even at birth the mechanism of the circulation and of breathing is so completely developed that these functions can proceed quite independently and without our further assistance. Were we obliged to give our constant attention to these two absolutely necessary functions, where should we find the time for any intellectual labor?

In other fields, however, it is not so easy for us. The child has to practice long before it can sit upright, and still longer before it can stand and walk. But having once thoroughly learned this feat, having made it completely our own, it is no longer necessary — at least under normal conditions — to give our supervision, our conscious assistance, to the equilibration of the body. This is maintained quite unconsciously, while the mind is engaged with other things. We can, for example, follow a process with strict attention while sitting or standing, without becoming upset or falling from the chair — unless perchance we fall asleep.

It is a most wonderful and advantageous physiological arrangement that just those vital processes which demand the most time, continuing as they do throughout our whole life, need no assistance from our consciousness, but are performed automatically.

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[1] A lecture delivered before the Verein zur Verbreitung naturwissenschaftlicher Kenntnisse in Wien. Translated from the *Schriften des Vereins*, Bd. xxxvii, by Guy M. Winslow, Ph.D.

It will now be my purpose to show how the preservation of the equilibrium may be accomplished, how we can stand and move without being conscious of the complicated mechanism brought into action, and yet without constantly falling. We shall also take occasion to mention derangements of this mechanism, for right here we shall find many indications which are important for the comprehension of normal conditions.

We begin with the simplest process of standing erect:

> Sehe jeder, wie er's treibe,
> Und wer steht, dass er nicht falle.

What, then, happens when we remain quietly standing erect? In order to do this a great number of our muscles, indeed nearly all the muscles of the trunk and lower extremities, must coöperate. The impulse for this coöperation is transmitted to the muscles from the brain; but in order to stimulate the muscles properly, the brain needs a number of external impressions, sensations, which incite the impulse, and regulate it. We shall then have to inquire how the muscles must coöperate to produce the erect position. We shall endeavor to penetrate farther into the secret of the complicated apparatus of the brain, which works so nicely, and, finally, we shall turn our attention to those sensations which furnish the necessary material for this part of the activity of the brain.

I have mentioned above how great a number of muscles is required simply for standing. It is not necessary, however, that all the muscles concerned should contract; if all our muscles were in a state of strong contraction, making the body stiff and motionless, we should be as unstable as a broomstick which had been placed upright on the floor. It is, rather, necessary that each of these muscles contract with a certain strength, up to a definite point, so that each little inclination of the body be counteracted by a stronger contraction of the opposing muscles, while others are correspondingly relaxed.

There is needed for this a very finely calculated and graduated intensity of action by each of the components of motion, a process which is designated as coördination of the muscles, in this case as static coördination.

Let us again take the stick of wood, which would not remain standing before, and fasten a number of strings to its upper end. Now let us set it up again and pull slightly in different directions, laterally, and a little downwards. Probably it will at first fall over to one side toward the strongest pull, but if we modify the strength with which it is drawn in the different directions, we shall finally cause it to remain quietly standing in a vertical position. A condition of equilibrium has been reached by the proper coördination of the forces acting, the same as occurs with a standing man through the coördination of muscles.

Intentionally I lay special stress upon this unusually important factor of coördination of the muscles, which takes a significant part in each muscular act, even though the result be unsuitable to the purpose which prompts it. Indeed, we may go still farther and say that wherever several factors coöperate for the attainment of a uniform result, a proper determination of the intensity with which each shall act is absolutely necessary. Without going into complex social conditions I may give an illustration from art.

If, in the well-known Seventh Symphony of Beethoven, the bassoonists conceive a desire to play fortissimo in the wrong place, the effect will be destroyed as much as if the contrabass were to play a very light piano in a place written forte. Each player finds certain signs with his notes, the dynamic signs of expression, which show him not what, but how, he ought to play.

The corresponding signs which make known to our brain how each muscle must act for the attainment of static coördination are imparted to it by different sense organs. As the first, though not the most important of these, I mention the touch sensations of the sole of the foot. If we stand, and still more if we walk, we feel the ground beneath our feet. It needs no long reflection to perceive how difficult simply standing would be for us if our feet were insensible. We can understand this easily, because we are able at any time to bring the sensations of touch and pressure in the sole of the foot before our consciousness.

Far more important, however, are sensations of whose existence many men know absolutely nothing, namely, those from the joints, tendons, and muscles. By the nerves from these organs the brain receives information in regard to their condition, but this takes place in such a way that these sensations do not generally overstep the threshold of consciousness. They serve almost exclusively automatic purposes, and would therefore unduly and uselessly burden our attention. But it is an established fact that we may be conscious of the muscular sense. We are conscious, for example, of the strength, the exertion which is required to lift a weight; indeed, we can estimate the weight of the object lifted by the strength expended, and distinguish the heavier object from the lighter. For this reason the muscular sense has also been called the strength sense. The pains of fatigue, or the strong muscular pains caused by cramps, are perceived by means of the same nerve tracts.

There are many who deny the existence of a muscular sense; for example, Wundt. He prefers to refer whatever is ascribed to this sense to the sensations of the central nervous system. But many facts, especially pathological conditions, incline us to admit a muscular sense.

Having now become acquainted with the existence of the muscular sense, we can comprehend that in this region we must seek the most important sensations which render possible the coördination of the muscles and standing erect.

The great significance which the joints and joint nerves attain in this process as a result of their position is self-evident. But these stimuli, transmitted from the locomotor apparatus, that is, the muscles, joints, tendons, etc., to the central nervous system, may perhaps be utilized in another way for the coördination of the muscles. E. Hering proposes the following: At each slightly energetic movement, for example the bending of the arm, those muscles which produce the opposite movement—the antagonistic muscles, in this case the extensor muscles of the arm — are relaxed; thus the nerves of these muscles are stimulated, and there results a certain reflex contraction of these opposing muscles. An excess of the intended movement is thus prevented. If this opposition, this restraint, be for any reason lacking, the movement becomes disordered and unsteady, as we indeed see in certain diseases.

Less striking, but yet not to be overlooked, is the rôle which the so-called visceral sensations play in the process under consideration. From all the viscera there are nerves which convey sensations to the spinal cord and the brain; of these sensations also we are, as a rule, unconscious, except when the organ from which they come is diseased. As soon as we become conscious that we have a liver, then the liver is usually diseased. The viscera are suspended freely within the body cavity; each change in the position of the body must then produce a greater or less displacement of the viscera. This displacement is not generally a matter of consciousness, yet an unconscious sensation is transmitted to the brain. It is evident, then, that the visceral sensations are of essential assistance in the preservation of the equilibrium.

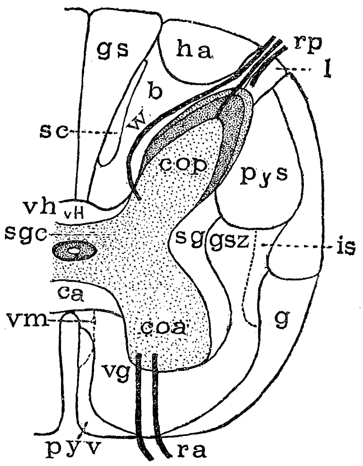

Fig. 1. — Transverse section of spinal cord. *b*, Burduch's column; *ca*, anterior commissure; *coa*, anterior horn of gray matter; *cop*, posterior horn; *g*, Gower's bundle; *gs*, Goll's column; *pys*, lateral pyramid tract; *pyv*, anterior pyramid tract; *ra*, anterior root; *rp*, posterior root of spinal nerve.

It will be in order to introduce here a brief anatomical note. We have thus far spoken of the sense of touch, especially in the soles of the feet, and of sensations from the joints, tendons, muscles, and the viscera. These are all perceived by means of nerves which enter the spinal cord through the posterior roots (Fig. 1, *rp*). If we examine a transverse section of the spinal cord (Fig. 1), we find about its center a reddish-gray mass (*cop* and *coa*), the gray matter, while the remainder of the section is made up of the white matter. This white matter consists almost exclusively of nerve fibres, which for the most part run longitudinally along the spinal cord. Thus, if we cut the spinal cord transversely, we have a countless number of cross-sections of nerve fibres. But, although even under the microscope the whole field of white matter appears quite homogeneous, we know that it is divided into a number of fibre bundles of varying significance and function. Thus we distinguish in each half section of the spinal cord about sixteen different regions.

The nerves mentioned above, and which are of significance to us, enter the spinal cord through the posterior roots, and take their further course to the brain, perhaps exclusively by way of the posterior bundles (*gs*) and (*b*), the lateral cerebellar tracts (*ks*) and Gower's bundle (*g*).

I would not have bothered you with these dry anatomical data if we were not to need them later.

I turn now to another class of sensations, which likewise are scarcely known to the non-scientific, since they, like the muscular sense, perform their function outside the sphere of consciousness, and become apparent only when they are irritated.

Under this head let us consider the inner ear, that part of the auditory organ which lies deeply buried in the hardest bone of the skull, the temporal bone. We find in this two principal parts; one has the characteristic form of a snail shell, and is hence called the cochlea; the other consists of three curved tubes which are connected in such a way that the two ends of each open into a small sac-like enlargement, the utriculus. These tubes are called the semicircular canals; together with the utriculus they form the labyrinth of the ear. If one imagines a plane passed through each of these three arches, it will be found that the three planes are perpendicular to one another. It is only when the cochlea itself becomes diseased or destroyed that a defect of hearing occurs. This effect is not produced by injuries to the labyrinth. In the latter case, on the other hand, very peculiar disturbances of the equilibrium are experienced. These facts were first demonstrated by Flourens. I cannot here go further into the very interesting investigations which were carried out later, especially by Golz, Breuer, and Ulach, among others, for the determination of the function of this little organ. Even in the lower forms, for example in the crabs, Kreidl was able to establish the same fact.

The result of this discovery, as well as the observation of diseases of the labyrinth in man, has taught us that this part of the inner ear, that is, the labyrinth, represents a sense organ which gives to the individual information in regard to the position of the head in space. This organ produces the sensation of turning, and thus controls the perception and maintenance of equilibrium. We have, then, acquired a sense of equilibrium, the peripheral sense organ of which is to be found in the labyrinth, and which transmits its sensations to the brain by means of a part of the auditory nerve.

The method of action of this sense organ is as follows: both in the utriculus and at places in the semicircular canals, the ampullæ nerves terminate in cells from which cilia project into the inner lumen; there is also in the utriculus, at the end of these nerves, a cluster of fine crystals — the otoliths. The utriculus and semicircular canals are filled with a fluid, the endolymph, which is agitated by each movement of the head, and which thus bends the cilia. The otoliths contribute to the reënforcement of this stimulation. At the beginning of a turn of the head in the plane of one of the canals, the fluid, as has been shown by Breuer, lags behind, and so strikes in the opposite direction against the cilia.

The task of maintaining the equilibrium is, again, essentially lightened by the sense of sight. This point hardly needs a detailed presentation. The impressions of vision give us information as to any change in the position of our body, and every one knows that we stand or move unsteadily in the dark or with closed eyes. And here I will emphasize the fact that the sensations from the eye muscles are also essential components of the mechanism of equilibration.

Recapitulating, then, we may say that the following sensations coöperate for the equilibration of our bodies: touch sensations, which are perceived by means of nerves from the joints, tendons, and muscles; sensations from the labyrinths; and, finally optic sensations All of these sensations are collected and employed in the brain with such a resulting effect upon our body musculature that the desired object, the preservation of equilibrium, is attained.

We have now to investigate further what part of the brain is intrusted with this important and complicated function.

First, I may again point out that we are, as a rule, entirely unconscious of many of the sensations concerned in this process. And since we are justified in concluding that, in order to become conscious, sensations must pass to the cortex of the cerebrum, we are from the first inclined to look for the organ of equilibration which controls the coördination of the muscles elsewhere than in the cortex of the cerebrum. There is also a series of facts which makes it highly probable that the part of the central apparatus sought is to be found in the cerebellum.

The cerebellum is an organ which is clearly separated from the rest of the central nervous system, and which in its finer structure differs essentially from all other parts of the brain. It has also a special and peculiar function. In comparison with the other parts of the brain it is not proportionately well developed in all animals. In mammals and birds the cerebellum is not only relatively large, but its surface is increased many times by numerous delicate and usually deep parallel furrows. In the Amphibia and many reptiles, on the contrary, it is reduced to a simple small ridge. While the first-mentioned groups require very sensitive and complicated muscular action for the maintenance of the equilibrium while standing, running, and flying, in the other groups a much simpler apparatus suffices for mere crawling or jumping. In the fishes the cerebellum is larger than in the Amphibia, yet with the exception of one of the cartilaginous fishes it is still smooth. Frogs, it is true, swim, but with far less rapidity and precision than fish. Thus we actually find a certain parallelism between the size of the cerebellum and the delicacy of the muscular coördination.

Another anatomical fact is now to be considered. We are acquainted with certain tracts of the spinal cord which we know convey to the brain a part of the sensations necessary for the preservation of the equilibrium. We know that, directly or indirectly, all of these tracts are intimately connected with the cerebellum, and some of them pass entirely into it. No connections between the nerve fibres arising from the labyrinth and the cerebrum are known, but the labyrinth has many direct and indirect nervous connections with the cerebellum.

It is found, therefore, that, with the exception of the optic nerve, all those sensory tracts which are used in equilibration collect in the cerebellum. And there certainly are connectives between the optic nerve and the cerebellum, yet in regard to this our knowledge is very incomplete. These are the purely anatomical considerations which point to the cerebellum as the center of coördination or equilibration. But physiological experiment also shows us facts which lead to the same conclusion.

Only a carefully performed and rightly interpreted experiment can inform us as to the function of this part of the brain. Erroneous observations and interpretations have ascribed to the cerebellum all possible functions; for example, the seat of the soul, the emotions, the memory, and so forth.

If one wound the cerebellum of an animal badly, or if he extirpate a portion of it, there is no proper regulation of the muscular contractions, and there is a decided disturbance of the equilibrium, resulting from the defective innervation of the muscles. An animal thus treated makes the most senseless and inopportune motions without accomplishing its purpose; yet it hears and sees, and its intelligence appears not to be interfered with.

Similar phenomena occur in men having diseases of the cerebellum. As we shall return to this point again, I will here only briefly note that, in most cases of serious disease of the cerebellum, disturbances of the equilibrium and dizziness are present.

We have found, to summarize the above, not absolutely certain proof, but still a number of important reasons which fully justify us in searching in the cerebellum for the central apparatus for muscular coördination, and the resulting preservation of equilibrium.

Thus we have solved a part of the problem presented to us. We can now represent diagrammatically (Fig. 2) the whole apparatus which must take part in the process of equilibration. To the cerebellum (*k*) there are transmitted various sensations coming from the skin (*hs*), the muscles and joints (*ms*), the viscera (*vs*), the labyrinth (*l*), and from the eyes (*a*). All these sensations are combined in the cerebellum into a single resultant nervous impulse which influences or modifies the movements incited by the cerebrum in such a way that the coördinated effect desired is attained; so that the different muscles *m* and *m* contract in the proper manner. This may be stated somewhat as follows: The cerebellum does not — on the basis of the sensations conveyed to it — apportion the necessary stimuli to the muscles concerned in an action separately, but distributes it as a whole to the muscles concerned.

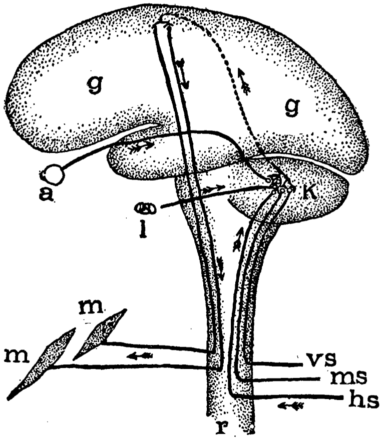

FIG. 2. — Diagram of nerve tracts employed in coördination for maintenance of the equilibrium. The arrows indicate the directions of the nervous impulses. *a*, eye; *g*, cerebrum; *k*, cerebellum; *l*, labyrinth; *hs*, *ms*, *vs*, nerves for impulses from skin, muscles, and viscera; *m*, muscles.

In the above diagram we may consider the relations of certain sensory nerves to the cerebellum, as well as to the tracts which receive their impulses from the cerebellum and transfer them to the muscles, to be definitely made out. But it is still a question where the cerebellum exerts its regulatory influence upon our movements; where we have to suppose the connection, here represented by a dotted line, is really to be found. But there are also many other gaps in our knowledge of our central nervous system; and for the object at present under consideration this question seems not to be of essential significance.

It is now to be investigated how this coördinating apparatus may act under different circumstances. The simplest task is that with which we have started out, namely, the maintenance of static coördination, that is, the preservation of equilibrium while standing erect under perfectly normal conditions.

If any one attempts to stand erect and perfectly motionless, he finds that he is unable to do so. A smoked plate has been placed horizontally above a person trying this experiment in such a way that a point projecting from the cap touched upon the plate. Each movement of the head is then registered upon the smoked plate, and an irregular zigzag line is obtained as the expression of the oscillations of the body. The sway from side to side amounts to one and one-half centimeters; that from before backwards, to two centimeters. The oscillations increase with fatigue and become sensibly greater if the experimenter closes his eyes, or if any other of the factors concerned in the process of equilibration is eliminated. And the oscillations become yet greater in certain diseases, accompanied by the destruction of coördination. We learn from this experiment that it is not possible for us to stand perfectly quiet, but that we are always balancing ourselves within certain limits. By this process certain muscles are brought much into use, and after a time they become greatly fatigued. Then we change our position a little, so as to bring other muscles into play, and at least in part to relieve those exerted earlier. We also learn from these experiments that it is more difficult to maintain our equilibrium while standing if any of the sensations usually participating in the process are inactive. Closing the eyes results in greater oscillations, and anesthesia of the soles of the feet, as I have already remarked, essentially increases the difficulty of standing. The result of a loss of the muscular sensations, or of the sensations from the labyrinth, would be still more serious, while the greatest disturbance of all occurs when several of the component sensations are simultaneously wanting, especially if, as the result of disease, they deceive us by false sensations.

A healthy man under normal conditions maintains his balance while standing in spite of the above-mentioned oscillations, and he is quite unconscious of this process and the attendant difficulties. But if any essential factor of the apparatus for keeping his balance be eliminated or altered in its action, he feels the difficulty of performing the task properly, a feeling which we designate as dizziness. Dizziness is the sensation of the loss of equilibrium combined with the feeling of difficulty in counteracting this loss. As will be easily understood, fear is often associated with dizziness.

We shall, then, find quite different causes for the occurrence of dizziness, according to the part of the balancing mechanism which has its functions destroyed. But first I must briefly mention a peculiar kind of dizziness which is not preceded by any injury to the nervous system, namely, physical dizziness.

We must constantly remember that the process of equilibration usually takes place unconsciously. But if we find ourselves upon a narrow plank lying across a brook, or on the edge of a precipice, we become conscious not only that we have a certain difficulty to overcome in order not to fall, but also that such a fall would be attended by very serious results to us. We attempt, therefore, by voluntarily exerting all our muscles, by extending the arms, and in other ways, to render the process of keeping our balance easier. But in reality we aggravate the difficulty and perhaps finally fall. Fear makes us especially clumsy. It is as if one were riding a beast of burden along a narrow mountain path. As is well known, in such a case one should give himself over to the animal, which is accustomed to travel safely; but if the rider becomes afraid, and tries to guide the animal with the reins, it may easily happen that both perish together. In this figure the animal represents our unconscious coördination, which we destroy when we try consciously to assist it.

If we return now to our diagram, it will essentially aid us in our study of the different kinds of dizziness.

We will begin with the different varieties of sensation which participate in the maintenance of the equilibrium. In the disease of the spinal cord known as tabes dorsalis the posterior roots are first affected. The sensations from the muscles, tendons, and joints then become reduced or arrested. I notice that occasionally the tactile sensations of the skin do not suffer until late, or perhaps not at all; while, on the other hand, the destruction of the visceral sensations is not rare.

As a consequence of the loss of the muscular sense, a man afflicted with this disease shows peculiar symptoms. His motions are not regular, not properly gauged: in walking his feet go shuffling and bumping along, while if he sits they will cross; again, one foot is lifted much too high in the air, though at the same time he may not be able to send sufficient stimulus to his muscles to produce the contractions necessary for his purpose. This defect in the control of the muscular innervation is called ataxia, and since it is dependent on a disease of the spinal cord it is known as spinal ataxia.

This disease offers yet another phenomenon. During its first stages the patient is generally able to stand quite firmly, even though his feet be placed near together, thus reducing his stability as much as possible. But no sooner does he close his eyes than he begins to totter and become dizzy, finally falling, unless he is supported. The explanation of this phenomenon, known as Romberg's symptom (static ataxia), is to be found in the fact that in closing the eyes the control of the equilibrium dependent on them, a very important factor, is lost.

There is a particular kind of dizziness, called optical dizziness, which depends upon a derangement of the nerves of the eye muscles. Let us imagine that our eyes move without our being conscious of it. It will seem to us that the objects about us have changed their positions in relation to our body ; and since walls, trees, and pieces of furniture, which we know to be fixed, appear in a different direction, we conclude that our body has moved. This erroneous impression passes to the center of coördination, and is answered by a compensating movement of the body, which is naturally unsuitable; then we again feel a loss of balance. Thus is explained the uncertainty in standing and walking which is observed as resulting from many kinds of disturbances in the movement of the eye.

That dizziness also arises from the digestive organs, by means of the visceral sensations, is a fact well known to the laity. But the process here taking place is in no way clear to us.

The phenomena of dizziness and loss of balance, which have their origin in the ear labyrinth, the special organ of equilibration, are of particular interest. Here also we must distinguish whether we have to do with false sensations which are transmitted from this sense organ to the brain, or whether this kind of sensations is entirely lacking.

It is plain to see that the latter condition might easily be followed by less serious results than the former; for if the sensations from the labyrinth are lost, a more or less complete compensation may be made by the other senses. But the central nervous system will be led into error by false impressions from this organ, and thus be perplexed, even though the control of the other senses remains intact.

I will now call attention to the familiar phenomenon of whirling dizziness, which is produced when we turn swiftly about the long axis of our body. We have seen that the nerves terminating in the labyrinth are stimulated by the flow of the liquid contained in it — the endolymph. But after turning rapidly this fluid does not immediately come to rest, as we see when a vessel containing water is rapidly rotated and then suddenly stopped. By this continued movement of the endolymph the nerve ends are stimulated for a time after the body has entirely ceased to move. False sensations are thus produced which give us a wrong impression of the actual movement of our body and cause dizziness — the whirling dizziness.

The same effect is obtained in whatever direction the turning takes place. From quick movements upward or downward, also, similar results occur. In America, where very tall buildings are now constructed, the use of elevators is frequently attended with dizziness, by which elevator boys are particularly affected.

Seasickness can also be traced, at least in part, to similar conditions. But I will here observe that the viscera also, though in a much less degree, may participate in the production of whirling dizziness and seasickness. If the head be held still, and quick rotating motions be made with the trunk, by which the freely suspended viscera are set in motion, a slight dizziness is often felt.

A peculiar pathological phenomenon, known as Menière's disease, or better as Menière's symptom complex, here deserves special mention. This malady is characterized by dizziness and a buzzing and snapping noise in the ears. One concludes, with much reason, that in such a case the ear labyrinth is directly or indirectly injured. In some cases of this kind, bleedings have been found in the semicircular canals, and fissures in the temporal and other bones.

A complete absence of the sense of equilibrium is found in a number of deaf-mutes, in about fifty-six per cent of whom the ear labyrinth is entirely degenerated. Such deaf-mutes go tottering and stumbling along with their legs spread far apart; if, while in the water, they become submerged, they lose their orientation in space. But, as can be easily understood, and as has been demonstrated by Kreidl, they are free from whirling dizziness; likewise (according to the investigations of Pollak) they are immune from galvanic dizziness, which is produced in a normal individual when a galvanic current is passed through the head.

We have seen that through the abnormal or arrested activity of a number of sensory nerves, disturbances of equilibrium and dizziness are produced; we must now go farther and investigate the action of the central nervous system in this relation.

We here pass to so wide a field of observation, however, that I must limit myself to indicating only the rudest outlines.

The cerebellum has been recognized as the most important central organ of equilibration. Severe diseases of the cerebellum are therefore characterized by dizziness and loss of equilibrium. The gait of one thus diseased is peculiarly unsteady, best compared to that of a drunken man. In this case also irregular motions result, but still they are quite different from those I have described for tabes. This kind of defective motion is called cerebellar ataxia.

But a glance at our diagram shows that another part of the central nervous system plays a rôle in keeping the balance. We are next to consider that nerve tract by means of which the cerebellum exerts its regulatory influence upon the tract controlling motion.

In the diagram (Fig. 2) I have indicated this tract by a dotted line, in order thus to express the fact that its course is not perfectly known to us. But notwithstanding this somewhat unsatisfactory condition of our knowledge, we must expect that similar phenomena can be produced from different places in the brain.

Dizziness with severe disturbances of the equilibrium may occur, the brain parts concerned being severely diseased. It is sufficient for them to experience a changed or imperfect nutrition. This occurs, for example, with a general loss of blood, anæmia, or when the loss of blood affects the brain alone; in cases of this kind the symptom increases when the body is quickly raised to an upright position, and decreases when it is placed horizontally.

In a similar manner the nourishment of the brain is interfered with by certain poisonous substances, many of which, such as tobacco and alcohol, especially affect the balancing apparatus. The dizziness and unsteady motions resulting from nicotine poisoning are well known, and yet more familiar are the staggering movements following too free indulgence in alcoholic drinks. From the great similarity which exists between these symptoms and those of cerebellar ataxia, one may perhaps reasonably conclude that the effects of alcohol are more detrimental to the processes of nourishment in the cerebellum than to those in other parts of the brain.

Finally, mention should be made of numerous other circumstances which may interfere with the circulation in the brain, and by which, again, dizziness may be caused. Here belong, for example, epileptic dizziness, the feelings of dizziness which are often observed at the beginning of acute contagious diseases, and many other cases.

According to the plan which we have thus far been following, those derangements of equilibrium which originate in the locomotor apparatus should now be considered. Here the conditions are essentially simpler. If a muscle which is of importance in standing, or a whole group of such muscles, become paralyzed, the patient is no longer able to stand erect. Even a partial paralysis of such muscles will be sufficient to render standing, without external support, impossible. The result is exactly the same in whatever part of the locomotor apparatus the cause of this paralysis lies; be it in the muscles, nerves, in the spinal cord, or in the brain.

My purpose was to show you in the merest outlines how we are enabled through our central nervous system to maintain our equilibrium. But I have also had a subordinate aim; I wished to illustrate to you by an example the method by which we arrive at conclusions in regard to such questions. You have seen how we have laboriously to collect the material from different sources; not only anatomy and experimental physiology are studied, but we must add to this a knowledge of pathological conditions. And this latter furnishes us with particularly important and instructive facts; therefore I have allowed myself to devote considerable attention to the pathological disturbances of equilibrium.

Finally, I wished to show you by this example how great a part of the functions carried on by our organism is performed entirely apart from consciousness. Our conscious activity is thus released from what would otherwise be a very considerable burden.

If, then, as I stated at the beginning of my analysis, it is difficult for man to exist, yet we should be thankful to Nature that a great part of the labor imposed upon us is made essentially easier by the organization of our central nervous system, and that time is thus given us to engage in higher intellectual pursuits.

Let us thankfully recognize the value of this gift.